Two functions of analogical reasoning in design. A cognitive-psychology approach

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A cognitive-psychology approach

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Abstract. On the basis of data collected in three empirical studies conducted on industrial designers, this paper identifies two different types of "spontaneous" use of analogy in design. Focus is on the first "stages" of analogical reasoning, i.e. construction of a target representation, and search and retrieval of a source.
At the action-execution level, analogies are used in order to solve the current design problem; at the action-management level, in order to make the action-execution process cognitively more economical. Differences between the uses concern their dependence on the routine character of the task, the distance between target and source, and their link with creativity and reuse (or case-based reasoning).
Keywords. Creative Design, Analogical reasoning, Case-Based Reasoning, Creativity, Industrial Design, Cognitive economy, Action-execution level, Action-management level, Control, Reuse

This paper studies different functions that analogical reasoning may have in a particular form of "ill-defined" problem solving, i.e. design. It examines the question from a cognitive-psychology viewpoint: focus is on the psychological processes which are implemented by designers and the mental representations involved. Multiple links exist with computational approaches to analogical reasoning and to design: such models have a heuristic value, and our results have implications for them, e.g. in the domain of CBR (case-based reasoning) applied to design.
Two characteristics of our research make it rather original with respect to other cognitive-psychology research on analogical reasoning. First, the retrieval of analogues by the designers studied is "spontaneous": the analogous sources used by the designers are neither provided

explicitly, nor cued. (In the analogical-reasoning vocabulary, a "source" is a problem/solution association related to a problem already solved, which constitutes the reference for the solution to the problem that is currently to be solved, the "target". The term "problem/solutions" or "problem/solution representations" was proposed in order to refer to both "problem/solution schemata" -i.e. representations of classes of problems and their solutions- and "particular problem/solution associations" -i.e. mental representations corresponding to specific problems and their solutions[1].) In most research on analogical reasoning, the experimenters provide explicitly and/or cue the analogues to be exploited. Rare are the studies conducted on tasks in which the use of analogues would be helpful, but in which both this utility and the particular analogues themselves are not given, or at least suggested, to the subjects. Second, our studies have been conducted on use of analogy in a daily work context, whereas analogical reasoning has mostly been studied in artificially restricted tasks. Only very few data have been collected on the use of analogy in "real" tasks, e.g. in professional activities accomplished in their natural work context, or in learning in natural school or other educational environments. Data analysed in this paper come from several studies conducted on different sorts of industrial, professional design activities, both in routine and in nonroutine tasks.

The main goal of this research is to understand how the first stages of analogical reasoning are conducted in human (design) problem solving, and which functions this form of reasoning may have in (design) problem solving, i.e. how and why a problem solver refers to analogical sources to solve a target problem. Knowing and understanding the cognitive aspects of an activity is one of the requirements for the development of both educational means and support systems. The use of analogies is indeed supposed to be a powerful means for design problem solving, and for the introduction of creative aspects in design. This assertion has to be made in a hypothetical form, because few empirical field studies have been conducted today on the topic. In this paper, three such studies are presented.

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The outset of the paper is as follows. Section 1 discusses the use of analogies. It puts our approach to analogical reasoning in design in the context of the main cognitive and computational models of analogical reasoning. Analogical reasoning in general will not be reviewed. The stages examined in this paper will be presented and confronted with those generally proposed. Section 2 presents three observational studies on professional designers working on real industrial design projects. The results are presented in section 3: two different types of analogy use have been identified in these studies: analogical reasoning can be used at the action-execution level, in order to solve the current design subproblem (referred to as "AE-analogies"), or at the action-management level, in order to make the entire action-execution process cognitively more economical (referred to as "AM-analogies"). This second type of analogy use (AM-analogies) was not yet identified in the research literature in the domain. The results are discussed in terms of the different stages of action execution (AE) and action management (AM) in which reference may be made to analogical reasoning. "Cognitive economy", which may function as a generative or as a critical constraint, is introduced and its role in the decision to search for an analogous problem/solution is presented. A comparison between the two types of analogy use, at a behavioural, descriptive level, shows that the differences concern the purpose of search for an analogue, the direction of analogue retrieval and the mode of search for an analogous solution to the current problem. One factor supposed to play a role in the different functions of these two uses is the routine character of the design task. The paper closes on a Conclusion, presenting an examination of the similarities and differences between analogical reasoning and reuse (or case-based reasoning), identifying on this basis another difference between the two uses of analogy, and formulating some conclusions.

1 Use of analogy. Different approaches

Research papers on analogical reasoning present this cognitive activity as frequently occurring and very important in both problem solving and understanding (often in the context of learning, but also in that of exposition or explanation). Greiner[2] asserts that "the phenomenon of analogy appears ubiquitous, playing an important rôle in essentially all modes of reasoning" (1988, p. 167).

According to Kedar-Cabelli[3], "a remarkable ability of people is to easily understand new situations by analogy to old ones, to comprehend metaphors, and to solve problems based on previously solved, analogous problems" (1988, p. 65). These assertions, however, are rarely backed up by data on human reasoning in "real" tasks (as opposed to the artificially restricted tasks used in most cognitive-science research, both in cognitive psychology and in A.I.). The available empirical data, besides, would not be of much use here. Most research in cognitive psychology in the domain of analogical reasoning uses sources provided by the experimenter, rather than generated by the "subjects" themselves -even if some authors study the "spontaneous noticing" of these sources, i.e., their "noticing" which has not been "prompted" by the experimenter (see e.g. [4] and [5]). So the results of the existing research as such cannot be used to draw conclusions about the role of analogical reasoning in real tasks, i.e., tasks in the "real world" where there are no experimenters providing analogous sources, or even hinting that an analogy could be useful for the current task.
Nonetheless, there are empirical studies on problem solving that may provide evidence for the spontaneous use of analogical reasoning in real tasks involving problem-solving activities. This paper examines such use in design problem solving, through data collected in observational studies on professional designers working on real industrial design projects.

Reviews of the current cognitive and computational theories of analogical reasoning generally distinguish two main approaches, Gentner's "syntactic"[6], and Holyoak's et al. "pragmatic"[7] approach. Recently, Keane et al.[8] have proposed, in their "solution generation theory", a common metatheoretical framework in which the different theories can be unified. All these authors focus on the mapping stage (Keane et al. also focus on adaptation[9]). As noticed already, due to experimental artefacts, few data exist on previous stages. Because we are interested by the earlier stages, we present these models only very briefly. Critical reviews and states of the art can be found, e.g., in [3], [10] and [11].
In Gentner's syntactic model (and its computational version[12]), the structure of the source and the structure of the target determine if there is an analogical relationship between the two, and these

structures guide the mapping which allows this relationship to be exploited. In the pragmatic approach, the structure of target and source is important, but the causal nature of the relations between the corresponding elements in these structures is the determining element in the definition of analogy —and in triggering off analogical reasoning. Because causal relations depend on the context and/or the use of target and source, this approach is qualified "pragmatic". Convinced as we are that goals play a predominant role in human problem solving, we cannot adhere to Gentner's theory, and we advocate the type of model proposed by Holyoak et al. and Keane et al.

If these main approaches differ on various points (especially with respect to the nature of the constraints on analogical mapping), they rather concord on the main stages they distinguish: retrieval, mapping, adaptation and side-effects (i.e. learning through induction, and/or other updating of memory).

Some authors also mention the construction of a representation of the target, which plays, in our view, a very important role with respect to the analogical reasoning properly speaking. Wolstencroft[13] proposes as first stage "identification", during which a person "[identifies] that analogical reasoning may prove useful". This stage is rarely explicitly considered by other authors. After the representation-construction stage, we distinguish a search and a retrieval stage, or search as a first process in the retrieval stage. A person who has to solve a problem may look for similar, analogous problems (after one has made out that one does not know the problem, or only if one does not find another way to solve the problem -see below, §3.4, and [14] for a brief discussion of the "conditions of reuse"). Holyoak and Thagard[7] also propose that the attempt to solve the target problem initiates search, implemented, in their model, by rule-directed spreading activation.

So, we propose the following stages: representation construction, search & retrieval, mapping, adaptation and side-effects. In this paper, focus is on the first stages, i.e. on representation construction, search and retrieval.

The function of analogical reasoning is generally not stated explicitly: in problem solving, analogies are -implicitly- supposed to be used "to solve the problem". In our studies, in addition to this use of analogy at the "action-execution" level, we identified its exploitation for "action management". This second function of analogical reasoning served to organise the global problem-solving activity as economical as possible from a viewpoint of cognitive cost. The present text examines these two functions of analogical reasoning in design problem solving

2 Three field studies: how are analogies being used in design problem solving?

Through the years, we have conducted various observational studies on designers[15]. Three of these studies, which have provided data on use of analogy, will be referred to below. Even if, at the start, they did not focus especially on analogical reasoning, during data analysis the importance of this form of reasoning in design problem-solving was discovered.
Table 1 presents the three studies at a glance. Only the more or less routine character of the different tasks and the data-collection method which has been used will be further described in the text.

2.1 Routine character of the tasks examined

A.I. researchers working on design often distinguish "routine" (or "familiar") and "nonroutine" design (or "creative", "insightful" or "innovative" design [16,17]. In cognitive psychology, the opposition routine - nonroutine is found in global analyses of problem solving. This text adopts a distinction made by Mayer[18], that we judge particularly clear: "routine problems are familiar problems that, although not eliciting an automatic memorized answer, can be solved by applying a well-known procedure. Although the problem solver does not immediately know the answer to a routine problem, the problem solver does know how to arrive at an answer. For example, the problem 888 x 888 is a routine problem for most adults. In contrast, nonroutine problems are unfamiliar problems for which the problem solver does not have a well-known solution procedure and must generate a novel procedure." (p. 40)

Note that the "routine" or "nonroutine" character of a design task depends on the designers' knowledge with respect to the "problem" they are confronted with, and on other characteristics of the problem situation. A "nonroutine" task for a designer may constitute a "routine" task for a colleague. This second designer may retrieve pre-existing procedures leading to the answers, or may not even need to proceed with "problem solving" for the execution of the task, if "simple" retrieval of the required answers is sufficient for her or him to execute the task.

Among the three tasks examined here, one tended to be nonroutine: it was the composite-structure design task (CS). It indeed consisted in designing a completely new type of antenna for satellites, i.e. an "unfurling" antenna (whereas before, antennas were rigid). The two other tasks (Mech. - Mechanical, and SW - Software) were rather routine tasks for the designers observed, even if they included various aspects (subproblems) which were new for them, and asked for innovation or creativity on their behalf.

2.2 Data collection: Observation and Simultaneous verbalisation

All three studies used the same method. In each study, observations were conducted, during a period of several weeks, on a designer involved in his task (all designers were male). These were full-time observations in the Mech. and SW studies; in the CS study, observations were conducted at a rate of 3 to 4 days a week. The designers' normal daily activities were observed without any intervention, other than that, before we started to observe a designer, we asked him to verbalise his thoughts, all during his problem-solving activity, as much as possible[19]. We took notes on these verbalisations and other actions, and collected all documents which a designer produced during his work.

N.B. We took notes, because making audio or video tapes during the observations would have been possible, but the analyses of more than hundred hours of tapes would not!

Some remarks might be useful about the "verbalisation" technique. Researchers interested in mental activities often ask their subjects to "verbalise their thoughts" or to "think aloud", i.e., they ask them to report the information they take into consideration, the choices they are confronted with, the criteria used to take a decision, their reasoning, their hesitations, their questioning past decisions, etc[20].

There is an essential difference with "introspection", the method used in psychology around the century -and still often used by researchers, even psychologists, thinking and stating that they do "protocol studies" using "verbalisation".

Introspection consists in commenting on one's own mental activity, or on the information used - whereas what is asked to be verbalised is the information attended to which has been generated by the task-directed processes one is involved in -in so far as this information may be made explicit, but that is another problem. If researchers are interested in a mental activity, e.g., the problem-solving activity underlying a design activity, they do not want to collect designers' comments or descriptions, which give opinions about, or rationalisations of, the designers' mental activity. The data they want to obtain are the direct traces of the information used in the mental activity, which are indirect traces of the internal stages of the cognitive process underlying the activity. The next step is that the researcher analyses these data, according to strict rules and methods. One does not want the "subjects to speculate and theorize about their processes … [One wants to leave] the theory-building part of the enterprise to the experimenter. There is no reason to suppose that the subjects themselves will or can be aware of the limitations of the data they are providing [when probed to proceed to introspection]." (Ericsson & Simon[23], p. 221)

Of course, the use of verbalisation is submitted to several conditions (see [22] or, for a short presentation, [21]).

3 Two types of analogy use: "Action-Execution" (AE) and "Action-Management" (AM) analogies

Analogies were used in two different ways in these studies. These two types of analogy use identified in the studies are called "Action-Execution" analogies (AE) and "Action-Management" analogies (AM). The first one is the "classical" example of analogy use in problem solving; the second one has not been described as such in the literature.

Before presentation of these results in more detail, we need to describe the theoretical framework in which the main distinction introduced -i.e. between action execution and action management- finds its source.

3.1 Articulating design actions: two levels, action execution and action management

A distinction is made between an execution level where design problem-solving actions are "proposed" and "executed" and another, control level where a "selection" is made among the actions proposed; at this management level, control also makes "calls for action proposals". The two levels are structured according to the iterative sequence presented in Table 2[17].

This approach underlying our "opportunistic model" of design (it is the organisation of design that is "opportunistic", not the model!) is inspired by Hayes-Roth et al.[22], [23] (for our model, see [17], and, for some modifications, [24]).

3.2 "Cognitive cost": the main selection criterion

The analysis of the data obtained in Study Mech.[17], led us to propose "cognitive cost" as control's main action-selection criterion: if several action proposals are made, control will select the action which is most economical from a cognitive-cost viewpoint.

Next to functioning as a critical constraint, "cognitive economy" may also function as a generative constraint. If control policy favours cognitive economy, control might, in its call-for-action-proposals stage, make a call oriented towards cognitive economy.

Let's have a look at control making such a call. Both control-knowledge sources and knowledge sources at the action-execution level may react (these "knowledge sources" correspond to Hayes-

Roth's "specialists"). A control-knowledge source proposing an economical action could be the heuristic "Exploit the just developed solution in order to solve related problems which remain to be solved". If this heuristic is adopted, search for "related problems which remain to be solved" will occur. In parallel, action proposals are probably made by action-execution knowledge sources, e.g. global and local plans. For routine design tasks, designers may possess a -generally hierarchically structured- global-task plan[17]. Even if the actions proposed by such plans may be supposed to be "economical" from a cognitive-cost viewpoint, there may be more economical actions, proposed by other knowledge sources. If accepted by the control, such action proposals then lead to "plan deviations". Visser[27] presents six of such sources of plan deviation, identified through the analysis of the specification actions which did not match the mechanical engineer's global plan. These plan-deviation sources underlay our analysis of the design activity as opportunistically organised.

An example of such an opportunity is the following. Information looked up for the current design action may be used for another action because it is considered from a viewpoint other than the one required for the current action. Being able -but also prone- to adopt different viewpoints on the same information is characteristic for experts.

Both types of analogy use are examples of another opportunity, i.e. exploiting mental representations of design objects activated by the representations used for the current design action. Indeed, analogy is one of the activation-guiding relationships which, if they exist between two sets of representations, may lead to a switch between the design-object representations (the other activation-guiding relationships identified are prerequisites and interaction)[27].

3.3 "Action-Execution" (AE) and "Action-Management" (AM) analogies

Thus, analogies were used in two different ways in the tasks studied. The first type, Action-Execution analogies (AE), corresponds to the analogical reasoning which has already been identified often in the literature, even if mainly in experimental, restricted settings in which the analogous "source" was provided explicitly, or its existence was cued, to the subjects. It is the exploitation of an analogical relationship between two mental problem/solution representations, in order to solve the current target problem at the action-execution level. These AE-analogies have mostly been observed in the study conducted on the composite-structure design task (Study CS)[1].

The second type, Action-Management analogies (AM), has been observed in the two other studies (a mechanical functional specification task, Study Mech.[17]; and a software design task, Study SW[18]). It also consists in exploiting an analogical relationship between two problem/solution representations, and one may also consider that it is used in order to solve a "problem" -however, the problem in question is not at the action-execution level, but at the action-management level: it is a metaproblem which may be stated as follows: "How can I organise my activity as economical as possible?".

Except when explicitly specified otherwise, the term "(target) problem" will be reserved in the rest of this text for "problems" at the action-execution level.

These two types of analogy use are going to be described below.

3.4 Action-Execution (AE) analogies. Analogical reasoning for solving the current design problem

This is the "classical" example of analogy use in problem solving.

The designer has decided to solve a problem pb_n (see Figure 1) and looks in memory for an analogous problem already solved.

N.B. It may seem strange that, despite the big amount of research conducted on analogical reasoning, psychologists do not know under which conditions problem solvers apply analogical reasoning to solve a problem: do they so as one of their first attempts, or only after having tried, without success, one or more other approaches, especially after having tried to reason on the basis of a problem-solving schema? One may formulate the hypothesis that concrete, specific knowledge is used before abstract, general knowledge -an assertion which many authors in the domain of case-based reasoning (CBR) advance using no any empirical basis, or referring to not further specified "psychological data". One may use as an argument for this hypothesis the result from research on analogical reasoning that surface attributes are more easily accessible than structural features -but there are no data directly concerning this precise question: What comes first: general or specific knowledge? This is not surprising, given the late start of studies on tasks in domains where the use of specific knowledge is needed; until recently, psychological studies nearly exclusively concerned tasks requiring people to refer to only general knowledge[25,26].

In any case, the designer referring to analogical reasoning was not able to retrieve the particular problem/solution association corresponding exactly to his problem, i.e. "the answer to his question" -that is why psychologists speak of "problem solving" (cf. Mayer's[21] definition of "routine problems" given above). We observe that he tries to find an analogous problem pb_{n-m} for which he already knows the solution (sol_{n-m}).

This use of analogy has been observed in the CS study. The designer employed it especially in the conceptual-design stage. When elaborating conceptual solutions to design problems, he and his colleagues frequently were observed to be reminded of extra-design domain objects which implemented concepts (principles, mechanisms) which they judged might be useful for developing a solution to the current design problem.

An example is the following. When he is developing, in a discussion with colleagues, "unfurling principles" for antennas, both the observed designer and colleagues came up with ideas for conceptual solutions such as "umbrella," and other "folding" objects, such as "folding photo screen", "folding butterfly net", and "folding sun hat". Note that all these "folding" objects satisfy not only the "unfurling" constraint, but also another constraint on the solution, that of having a trigger mechanism allowing a complete unfurling of the object into a surface which is <u>rigid</u> (for another example, see [1]).

3.5 Action-Management (AM) analogies. Analogical reasoning for making the action-execution process cognitively more economical

In this case, analogy plays a role in the proposal, not of a solution, but of the next action to be executed.

The designer has just developed a solution sol_{n-1} to solve the problem pb_{n-1}. He then decides to take advantage of the fact that this solution is available at "low cognitive cost", to solve an analogous problem pb_n which is one of the subproblems of the global design problem which remain to be solved.

This type of analogy use has a function at the metalevel of problem solving: if there is no analogical or other semantic relationship that can been exploited, solving the target design problem is not prevented, it will only be less economical than if such a relationship had been perceived.

This use of analogy has often been observed in the studies Mech. and SW. The designers in these studies used it throughout their entire design task. Frequently they deviated from their action-execution plan in order to take advantage of the problem solving they had just accomplished. Thus, they used the solution procedure developed to solve the current target problem -taking advantage of it still being active in memory- in order to solve one, or sometimes even several, analogous problems which remained to be solved on the global design project. If they had stuck to their plan as regards its action-execution order, the solution would have had to have been constructed again later on, or possibly retrieved -but with difficulty- and then adapted. This construction, or retrieval+adaptation, would have a greater cognitive cost than adapting an already constructed solution that is still available.

In conclusion: for AE-analogies, the problem which is solved by reference to an analogue is the target design problem currently under focus; whereas for AM-analogies, it is a metalevel problem, i.e. the one of organising the action execution as economical as possible from the viewpoint of cognitive cost.

3.6 A factor contributing to the observed differences between the two types of analogy use: the routine character of a task

Table 3 confronts the two types of analogy use and shows the various aspects on which the two types differ.

One may notice that the use of the terms of "target" and "source" in the case of AM analogies is somewhat counterintuitive. Generally the "target" is the "problem to be solved", and the source is the "reference problem, already solved, and whose solution is adapted to solve the target". At a higher level, however, the "target" is the element (the problem) currently under focus, the element from which starts the search for a "source", i.e. another, related element, in memory or in another "inventory". Thus, in the case of AM analogies, the target is a problem already solved, and the source is a problem not yet solved: the direction of search, and of retrieval, is the inverse of the one generally observed.

The three studies in which the two types of analogy use were observed differ on various aspects. The studies were observational and not set up with the aim of comparing the tasks on the variable "type of analogy use". Therefore, we can only formulate hypotheses to this respect.

Among the task characteristics which may be relevant for the observed differences, we think that the routine-nonroutine character of the task was the most important one. AM-analogy use, i.e. exploiting the solution currently available in order to solve at low cognitive cost another problem, is only possible for a designer who knows which problems remain to be solved; thus, only for a designer who knows the structure of the global design problem. This is the case of routine problems. Therefore, it would be the routine character of the software and functional-specification design tasks that made it possible for the designer to anticipate the problems still to be solved, and to identify among them a problem related to the problem which he has just solved so that its solution (procedure) is available at low cognitive cost.

AE-analogy use (exploitation of analogy in order to solve the current design problem) does not seem to depend on the routine character of the task, but AE-analogies might contribute to the creative character of the activity in nonroutine tasks. Their use may indeed "invite" to develop new solutions if the analogical elements are retrieved from remote domains and/or if relations are established between domains not yet linked (as illustrated, e.g., by the example presented above of the "unfurling principles" for antennas). This might provide support for the relationship which is often presumed to exist between analogical reasoning and creativity (concerning design[27, 28, 29]).

4. Conclusion

In this final section, we will examine the similarities and differences between analogical reasoning and reuse (or case-based reasoning), identify on this basis another difference between the two uses of analogy, and formulate some, never final, conclusions.

4.1 Analogical reasoning and reuse: differences?

Reuse -or, in A.I. terms, case-based reasoning (CBR)- is the use of specific experiences —problem/solution associations if one restricts oneself to problem solving— or to be more precise: in order to solve a target problem, one uses problem/solution source elements at the same level of abstraction as the target.

It is often said to be particularly well suited to design problem solving[14, 30, 31,32, 33]. On the basis of cognitive-psychology data, Visser and Trousse[36] stressed the important role of exploiting specific experiences from the past in this type of problem solving, especially in nonroutine design (cf. the workshop organised at IJCAI93 on "Reuse of designs: an interdisciplinary cognitive approach"[34]).

The reasoning processes involved in the reuse of knowledge in problem solving are often related to, or even equated with, analogical reasoning -however, the nature of the relation(s) between the two is not yet clear. We see at least two important differences between reuse and analogical reasoning —or two important specificities of analogical reasoning compared to reuse.

The first one concerns the relationship between target and source which may be exploited to retrieve a source. In analogical reasoning, this relationship is, by definition, one of analogy -or, according to the authors, of other types of similarity- whereas reuse can also be based on other target-source relationships. If, as claimed by several researchers in the CBR community, the main constraint on a case (a source) is "usefulness rather than similarity" (see Kolodner[34], p. 155), a "useful" source can entertain another than an analogical relationship with the target.

The second difference seems the most important one. It concerns the mechanisms and strategies used to retrieve a source. The opposition often established by researchers in the CBR community between analogy referring to inter-domain, CBR to intra-domain, relationships is only a definitional one if one does not add a precision. That is, one may suppose that, in human reasoning at least, the same mechanisms are used to access a source, independently of its distance to the target. However, retrieval of distant knowledge may be more difficult, and require different strategies, e.g. for search. Such retrieval may require, e.g., that before one is able to establish that there is a relationship between the target and a source, one must construct a representation of the target at a more abstract level.

The underlying idea is thus that the difficulty to establish an analogy (or to reuse a source) is a function of the "distance" between target and source, as convincingly advanced by Johnson-Laird[35]. One argument is the "classical" result obtained in analogical-reasoning research that novices generally establish only surface analogies, whereas one has to become an expert to be able to base an analogy on "deeper", structural relationships.

It is, however, difficult to evaluate the "distance" in question, which does not depend on target and source independently of (the organisation of) a person's memory.

Rather than to conclude to differences between analogical reasoning and reuse, these two observations might be taken to sustain that analogical reasoning is a special case of reuse (or case-based reasoning), i.e. reuse of sources 1. whose relationship with the target is one of analogy (or other types of similarity), and 2. coming from a "remote" domain relative to the one of the target.

4.2 The two uses of analogy and the distance between target and source

With respect to the last point, analysing the two uses of analogy identified in our studies with respect to the plausible role of the distance between target and source in analogical reasoning (and reuse) leads to the identification of another distinction between these two uses.

The AE-analogy use observed in experimental studies is generally "intra-design-project" use of a source, or reuse, i.e. use of a solution developed during the current design project. In "real" design, however, elements from other, previously developed design projects are also reused. In both the study Mech.[17] and the study SW[18], we indeed observed such "inter-design-project" reuse. With respect to the reasoning involved, one may formulate the hypotheses that, compared to intra-design-project reuse, inter-design-project reuse is cognitively more demanding, and thus less frequently performed by designers. Even if it is difficult to evaluate a "distance" between target and source, one may suppose that distances between design objects involved in one and the same design project (intra-design-project reuse) are smaller than those between design objects involved in different design projects (inter-design-project reuse). That is why, even if analogical reasoning opens possibilities for creativity in problem solving, this creative aspect is not guaranteed: it is difficult to find solution elements from remote domains, or to establish new relations between elements.

In AM-analogy use, reuse is always intra-design-project reuse: a just developed solution is exploited to solve one of the design subproblems which remain to be solved. This means that according to the rate of AM-analogy use, the final design will have a more or less homogeneous structure -as a result of using, more or less frequently, a same solution structure for solving two or more different problems.

4.3 AM-analogy use: more or less interesting aspects

The homogeneity which may result from more or less AM-analogy use may be considered interesting for future reuse: indeed, the existence of different versions of a solution (various instances of a schema) offers several different, but similar sources, and may also provide various examples for adaptation of the solution[32].

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It is not only due to its consequences for future reuse that AM-analogy use is attractive. Our studies showed that its use during the design of specifications leads to specifications which -because of their homogeneity- are probably more easy to use: this may be reflected in the activities executed on their basis, i.e. the construction of the machine tool in the workshop (study Mech.), and the design and coding of the corresponding control program (study SW). A homogeneously structured program is besides especially interesting from comprehension and maintenance viewpoints.
N.B. The software designer's desire to ensure homogeneity in his design stemmed from an explicit preoccupation with the future use of this software. It introduced a constraint on his activity which strongly guided his work[18].
If this generation of homogeneous structure occasioned by the use of AM-analogies may be considered "interesting" in several respects, it turns out to be "uninteresting" from the viewpoint of creativity in design. This is due to the fact that it leads to maintain "old", rather than to introduce "new", possibly "creative", solutions in the design. The conclusion that analogy is not always positively correlated with (possibilities for) innovation may seem surprising[36], but it isn't: it is —was— based on analogy being equated with what has here been called "AE-analogy", whereas the conclusion is based on AM-analogy.

Let's briefly summarise the results and our interpretation of them.
On the basis of data collected in three field studies on design, two types of use of analogy were identified: for AE-analogies, the problem which is solved by reference to an analogue is the target design problem currently under focus; for AM-analogies, it is a metalevel problem, i.e. the one of organising the action execution as economical as possible from the viewpoint of cognitive cost. The possibility to use AM-analogies seems to depend on the routine character of the design task, whereas AE-analogies may be made in both routine and nonroutine tasks. AE-analogies may, however, contribute to the introduction of creative aspects in design. AM-analogies, to the contrary, introduce homogeneity in a design project, so remove a possibility of innovation, but present an opportunity for reuse. This observation was related to the distance existing between the domains of

target and source: AE-analogies may come from both connected and remote domains (cf. intra- and inter-design-project reuse), even if retrieval from a remote domain will be cognitively more demanding, and thus less frequent —or subject to more inaccuracy; AM-analogies are between target and source from the same design project, thus rather connected.

Analogy, which may be considered as a particular form of reuse, can contribute to the creative aspect of design, dependent on the type of analogy, at the action-execution or at the action-management level, which have different functions.

In conclusion: through the identification and analysis of two functions that analogical reasoning may have in design, this paper hopes to constitute a contribution to the knowledge on cognitive aspects of this type of problem solving, and thus, indirectly, to the development of educational means and support systems for (future) designers.

REFERENCE	Study CS	Study Mech.	Study SW
PRESENTED IN	Visser (1991)[1]	Visser (1988[37], 1990[38])	Visser (1987[39], 1988[16])
TASK	design	design	design
DOMAIN	Composite-Structure design: unfurling antenna for satellite	Mechanical design: functional specification of an automatic machine tool	Software design: control program for an automatic machine tool
ROUTINE-NONROUTINE	rather nonroutine	rather routine	rather routine
SUBJECT	1 designer specialised in composite-structure design	1 mechanical design engineer	1 software engineer
WORKING IN TEAM - WORKING ALONE	foreman of a team	foreman of a team	working alone
DATA COLLECTION	Observation and Simultaneous verbalisation	Observation and Simultaneous verbalisation	Observation and Simultaneous verbalisation
OBSERVATION PERIOD	9 weeks (at a rate of 3-4 days a week)	3 weeks (full time)	4 weeks (full time)
RESULTS			
TYPE OF ANALOGY USE	AE-analogies	AM-analogies	AM-analogies

Table 1. The three Visser design studies at a glance

(i)	call for action proposals
(ii)	proposal of one or more actions
(iii)	evaluation of the proposed action(s), leading to selection of one action
(iv)	execution of the selected action
(v)	back to (i)

Table 2. Articulating design actions: two levels, action execution and action management

Preprint of
Visser, W. (1996). Two functions of analogical reasoning in design: A cognitive-psychology approach. *Design Studies. Special Issue "Design Cognition and Computation", 17*, 417-434.

	AE-analogy use action-execution level	AM-analogy use action-management level
target	the current problem to be solved, pb_n	the problem just solved, pb_{n-1} + its solution just developed, sol_{n-1}
source	a problem solved in a more or less distant past, pb_{n-m} + its solution, sol_{n-m}	a problem which remains to be solved, pb_n
search for an analogue		
purpose of search	solve a particular design problem, i.e. the current design problem (pb_n)	solve the metaproblem of making the problem-solving activity economical
search mode	1. "do I know a related problem pb_{n-m} already solved?" if yes: retrieve pb_{n-m}, and adapt sol_{n-m} to apply to pb_n (resulting in sol_n) if not: 2. [other solution elaboration mode] (stay at problem-solving level)	1. "do I know a related problem pb_n still to be solved?" if yes: retrieve pb_n, and adapt sol_{n-1} to apply to pb_n (resulting in sol_n) if not: 2. "which action next?" (return to control level)
direction of search	from a problem to be solved to a problem already solved: from pb_n to pb_{n-m}	from a problem solved to a problem still to be solved: from pb_{n-1} to pb_n

Table 3. Comparison AE-analogy use and AM-analogy use

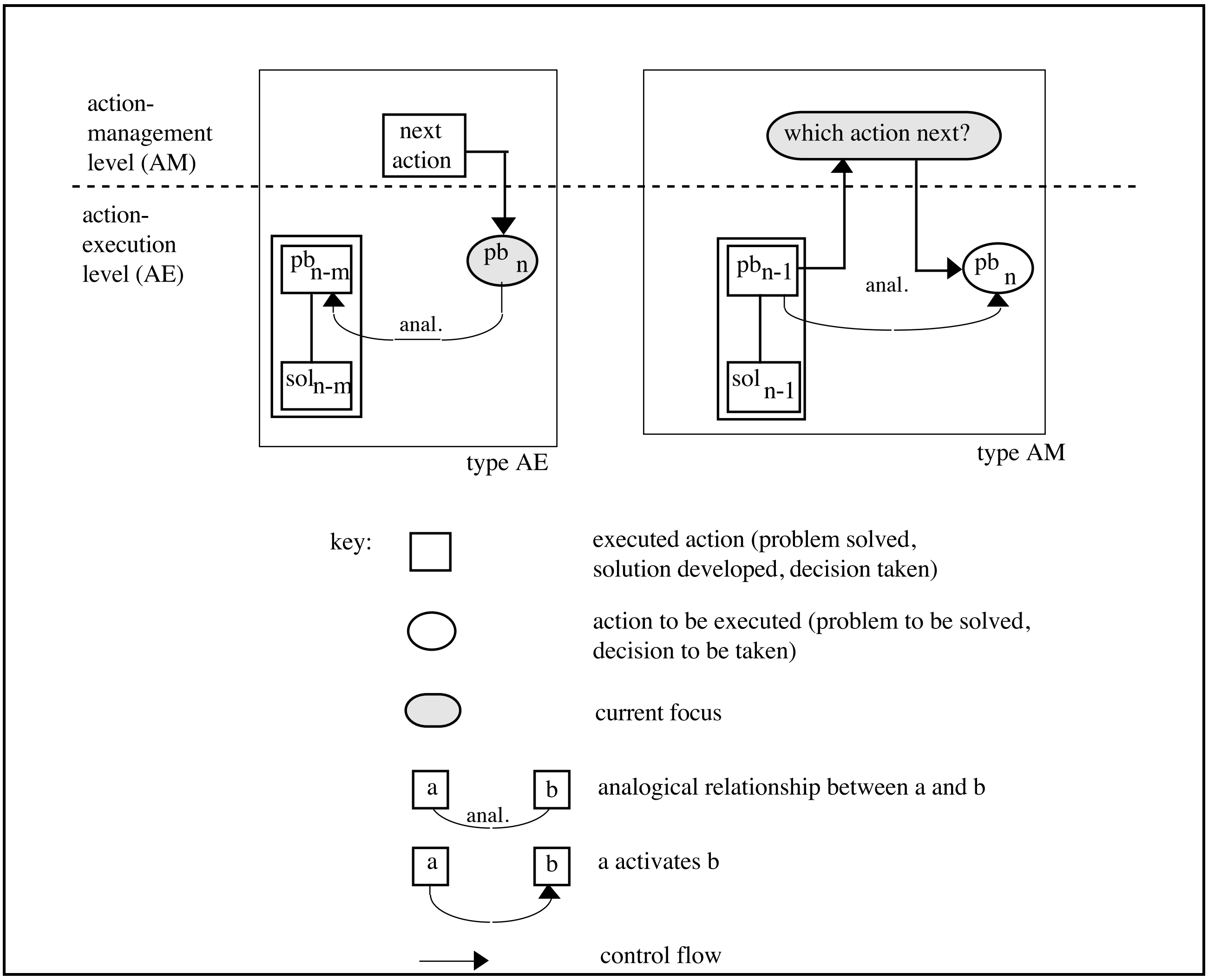

Figure 1. Two types of analogy use

Preprint of
Visser, W. (1996). Two functions of analogical reasoning in design: A cognitive-psychology approach. *Design Studies. Special Issue "Design Cognition and Computation", 17*, 417-434.

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